WIRELESS SECTION: CHAIRMAN'S ADDRESS

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(*Address delivered 7th October*, 1942.)

(1) THE WIRELESS SECTION

As I have been a member of the Wireless Section since its formation over 23 years ago, it is perhaps natural that I should spend a portion of this Address in reviewing the history of the Section, particularly for the benefit of the younger members. The membership of the Section is now over 1100 and more than 163 formal meetings have been held, while informal meetings have also been arranged from time to time to discuss topical technical subjects.

(1.1) Early History of the Wireless Section

Although the Wireless Section was not formed until early in 1919, a few papers on radio-engineering subjects came before The Institution from time to time. Even prior to 1900, three papers by Sir Oliver Lodge,[1] Sir William Preece[2] and Senator G. Marconi[3] described the laying of the foundations of practical wireless communication.

The suggestion that there should be sectional meetings of The Institution was first made by C. H. Wordingham during his term as President for the session 1917–18. He drew attention to the greatly expanding and highly specialized fields in which electrical engineering was then developing, and the tendency for those associated with the subjects of electric furnaces, wireless and X-ray work, to form special societies to meet their needs for the reading and discussion of papers on these particular subjects. Dr. W. H. Eccles records that a movement was actually started in 1916 for the purpose of founding a professional Society or Institution of Wireless Engineers somewhat on the lines of the Institute of Radio Engineers in the U.S.A. As a result of Mr. Wordingham's forceful arguments, the Council of The Institution adopted his recommendations and a beginning was made with the subject of wireless telegraphy. The Council appointed a committee to make the necessary arrangements, and the first meeting of this body took place on the 17th February, 1919, and was able to arrange immediately for four general meetings at which wireless papers or lectures were to be presented. It is perhaps not unnatural to find that the early material presented was in the form of surveys of development of wireless communication in the Services during the war years, from which the country was then in the early stages of recovery. It is very interesting now to draw attention to the fact that at the opening meeting of the first full session of the Wireless Section in November, 1919, Prof. C. L. Fortescue,[4] now President, presented a paper describing the development of multiple-stage valve amplifiers in their application to naval wireless-telegraph problems during the war.

The first Inaugural Address by the Chairman of the Section was given by Dr. Eccles[5] on the 24th November, 1920, in which he took the opportunity of reviewing the activities of the Section during its first full year, as well as to record some of his own original work on the thermionic valve oscillator. In the course of this session four papers were read at meetings and a discussion was held on "Long-Distance Wireless Transmission," a subject that has provided unusual opportunities for investigation and experiment since the possibility of transmitting wireless signals across the Atlantic was first demonstrated by Marconi in 1906.

The 1921–22 session was opened by Prof. Howe with an Address[6] in which he dealt principally with the properties of inductance coils. By this time the Wireless Section was well established, and meetings were held in each of the ensuing two years, and in addition some papers were published in the *Journal* without being read at a meeting. During the sessions 1923–25 E. H. Shaughnessy was Chairman, and he has the distinction of being the only Chairman to give two Addresses[7] before the Section; for although Prof. Howe was also Chairman for two successive sessions, he did not deliver a second Address. It is with great regret that I have to record the death of Mr. Shaughnessy last July. He was largely responsible for laying securely and wisely the foundations of the whole organization of the Radio Section of the Post Office, and The Institution owes him a debt of gratitude for being kept informed of the progress of the Post Office radio-communication system through his Addresses, not least among which was his account of the development of the high-power transmitting installation at Rugby. I believe it was largely Mr. Shaughnessy's foresight that reserved for Post Office use the very large area of ground at Hillmorton, near Rugby, which is now literally covered by a multitude of transmitting aerial arrays, the need for which could not have been generally realized when the purchase rights of the land were under discussion.

(1.2) The Proceedings of the Wireless Section

The first number of the *Proceedings of the Wireless Section* of The Institution was published in March, 1926, and the introductory note contains a report presented to the Council by the Committee of the Section. This report refers to the proposal which was then again being mooted in some quarters to form a new Institute of Wireless Engineers and suggested that such a step was unnecessary and would not be supported by representative and qualified wireless engineers. It was explained that an engineer with adequate wireless qualifications could become a Corporate Member of The Institution, and that other wireless engineers not reaching that standard were eligible as Graduates, and, as such, could attend all meetings of the Wireless Section as well as of The Institution. Furthermore, the Com-

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mittee recommended that while it was essential that the standard of qualifications for membership of The Institution should be maintained, more opportunity should be afforded to the physicist engaged in wireless work to become a member of The Institution. This recommendation was approved by the Council and has continuously been acted upon by the Membership Committee; it is particularly opportune to draw attention to it at the present time, when a large number of men engaged on wireless work would probably refer to themselves as radio physicists rather than as wireless or radio engineers.

Two other recommendations made in the above report were, first, that all papers and discussions of a wireless nature should be published separately as *Proceedings of the Wireless Section* as well as in the *Journal*; and, secondly, that the Local Centres should be encouraged to start Local Wireless Sections. For the first of these, every member of the Wireless Section must be very grateful. Fifteen volumes of these *Proceedings* were published during the period 1926–1940, and these contain a valuable record of the progress of wireless engineering research and development in a very compact form and free from the large mass of other papers published by The Institution and in which the wireless engineer has little more than general or passing interest. With the revision of the form of the *Journal* which was necessitated by paper-shortage considerations in 1940, the existence of these *Proceedings* formed a most valuable precedent for ensuring that the wireless papers were still published separately as Part III of the present-day *Journal*. It is very clear that, as regards the provision of scope and opportunities for publication, no separate society or association could serve its members better than The Institution has done during the past 16 years and still continues to do in a very satisfactory manner.

As to the second recommendation made by the Section Committee in 1926, it would appear that the Local Centres of The Institution have not found it practicable to inaugurate active Local Wireless Sections; for, while on some occasions papers from the Section in London have also been read at provincial cen res, I cannot recall that any wireless paper published in the *Journal* or the *Proceedings* originated at a Local Centre. It would seem desirable that renewed attention should be given to this matter, particularly in preparation for the large increase in activity that The Institution is likely to experience at the cessation of hostilities, on account of the greatly increased scope of radio communication and high-frequency engineering. I would draw attention to the fact that the original recommendation provided that as each Local Wireless Section was properly constituted, it would be entitled to elect or nominate one member to the Wireless Section Committee.

(1.3) Future publication

The present phenomenal growth in radio technique is likely to lead to increased specialization, but it is to be hoped that this will not lead too rapidly to sub-divisions of the Wireless Section into, for example, some dealing with specific wavelength or frequency ranges, or with different means of conveying the radio energy from one part of the equipment to another. To avoid this undesirable tendency it is important that all workers should realize the necessity for presenting papers which are in the nature of reviews of progress or surveys of particular spheres. One would like to encourage the younger members to do this from time to time, not only for the benefit of their contemporaries but also to enable the older members to keep acquainted with the progress of their subject, after it has ceased to be practicable for them to read all the numerous original papers. I hope that these remarks may be noted by those active workers who are in the forefront of radio research and development, and who will some time in the future be considering the preparation of papers describing their work over the past few years. It is conceivable that progress and development in some directions will have been so great and far-reaching that even the fundamentals of the subject may not be clearly understood by those who have not been in the secret during these war years.

One final word of advice may be given to those who will be responsible for preparing the papers to be offered to The Institution in the future. It may be assumed that when once the hand of the Censor is lifted there will be a flood of literature submitted for publication, and it is therefore essential that the papers themselves should be kept as short as practicable. But clarity should not be sacrificed in an attempt at brevity, and, in particular, care should be taken to ensure that all technical terms and expressions used are commonly accepted as standard and are well understood. Many of us are familiar at the present time with committees at which the proceedings take place in a sort of technical jargon peculiar to the particular subject, and in many cases not only words of one syllable but even words of one letter are in common use. Not unnaturally, the result is that the minutes of such meetings are often unintelligible to those unfamiliar with the particular subject under discussion. In the preparation of a paper an attempt is made to reach a much wider audience, and it is profitable to take considerable care in the choice and arrangement of its wording. The British Standards Institution has been responsible in this country for initiating and maintaining Glossaries of Technical Terms used in all branches of electrical engineering, and it is important that these glossaries should be kept up to date with such a rapidly advancing subject as radio communication and high-frequency physics and engineering.

(2) RADIO RESEARCH: THE WORK OF THE RADIO RESEARCH BOARD

It is not uncommon for your Chairman in his Address to review the progress of the particular field of radio work in which he has been engaged for the past few years, but I trust that the members will appreciate the difficulty in which I am placed in this respect. In my position at the National Physical Laboratory I have had the privilege of being associated with the work of the Radio Research Board from the time of its formation in 1920, soon after the inauguration of the Wireless Section. The Radio Research Board was established under the Department of Scientific and Industrial Research, to assist in the co-ordination of radio research work carried out by the Defence Departments and the Post Office, and to provide for research work of a fundamental nature in directions where it was lacking and where it would be likely to lead to useful applications. In the course of time the Board ceased to be responsible for the co-ordination of Government radio research, and the conduct of investigations of a

fundamental nature absorbed the bulk of its activities. At the same time the Board has always stressed the importance of bringing the research worker and the user of radio engineering into more intimate contact, and many of the phases of investigations on the Board's programme were determined from time to time by the needs of the Admiralty, War Office, Air Ministry, Post Office and the British Broadcasting Corporation, each of which departments was adequately represented by membership of the Board itself and of all its technical committees. The members of the Radio Research Board have all been eminent personages in the radio-engineering profession, and many of them have served as Chairmen of this Wireless Section, while some have occupied the presidential chair of The Institution.

The Radio Research Board makes its recommendations to the Department of Scientific and Industrial Research, which is responsible for providing the means and facilities for the conduct of the work; in recent years practically the whole programme has been entrusted to the Radio Department of the National Physical Laboratory for execution. This department comprises a main group at Teddington for laboratory work, administration and co-ordination with other departments of the National Physical Laboratory, while another group of staff for field investigation work is maintained at the Radio Research Station, Slough. Apart from the official reports of the Radio Research Board issued from time to time through H.M. Stationery Office, the majority of the investigation work has been described in papers and reports published by The Institution and other scientific societies. As an indication of the widespread nature of this publication it may be pointed out that of the 246 papers that have been published in the *Proceedings of the Wireless Section* during the past 16 years, no fewer than 80 of them have been presented by staff working under the auspices of the Radio Research Board.

Apart from the research and investigation work conducted under its auspices, the Radio Research Board has organized and maintained for 14 years past a service supplying a comprehensive series of abstracts and references which are published monthly in the *Wireless Engineer*. These abstracts are unique in wireless technical literature, and are greatly appreciated by radio engineers and research workers in all parts of the world.

A general survey of the progress of the work of the Board during the first 15 years of its existence was provided in a very interesting manner by my predecessor, Sir Robert Watson Watt,[8] in his Chairman's Address delivered in November, 1935. As already mentioned, it would be idle for me to attempt to supplement this survey, since for the past three years our efforts have been devoted entirely to the furtherance of the prosecution of the radio technical war in the manner in which we are considered to be most useful, and it is naturally not in the national interests to review the work involved. A conspicuous feature of our recent work has been to realize the fruition in direct Service application of all the long-term investigation sponsored for many years past by the Radio Research Board. The present value of pre-war fundamental work on direction-finding and ultra-short-wave propagation suitably orientated to meet present conditions is immediately obvious, but by now most of the apparently more academic subjects under investigation have suddenly been elevated to Service applications of the highest priority. Even some of the research items which had been abandoned in the past, as having little or no interest, have had to be revived to meet pressing demands, and it is often the fact of having already explored the technique and satisfactorily established the fundamental principles of a particular field that provides us with the advantage over the enemy in the technical conduct of the war. In some spheres the demand is for basic principles of design of apparatus and equipment which was developed originally as a research tool, and now has to be adapted to more practical application; in other spheres it is accurate measuring equipment and technique that is sought; while in yet other directions the request is for information that will define the present possibilities of radio communication, and more especially what these are likely to be in the immediate future.

All this assistance can only be provided quickly if considerable foresight has been exercised in the past in obtaining and training the necessary skilled personnel and using them to work patiently at the various problems involved so that they may acquire the experience and lay the foundations on which to build up the structure necessary to apply to direct operation. When one considers the magnitude of the expenditure which must be in operation at the present time on radio research and development work, it seems somewhat childish to point out that all the fundamental research which placed this country in the forefront of the world, in times of peace, was carried out with an annual expenditure represented by less than ½d. of the 10s. licence fee paid by broadcast listeners in this country.

(3) THE SPEED OF TRAVEL OF WIRELESS WAVES

(3.1) Introductory

I propose in this Section first to draw attention to some of the purposes for which we need to know the speed with which wireless waves are propagated under a variety of conditions, and then to survey the extent of our present available knowledge as to the precise value of this speed. At the outset I would point out that, although to a considerable extent the terms "velocity" and "speed" are used by physicists and engineers as if they were synonymous, they actually have different meanings in so far as velocity involves the direction of travel as well as the speed or rate of motion along that direction. Most, if not all, the work in the optical field refers to the velocity of light and not the speed of light, and it is possible that this lack of distinction between the terms is due to the fact, known long ago, that, except in a non-homogeneous medium, light follows an accurately rectilinear path, so that its direction of propagation is usually quite obvious.

The theoretical foundations of the possibilities of radio communication were laid by James Clerk Maxwell in a paper read before the Royal Society in 1864. In this paper Maxwell showed that any change in an electromagnetic field produces a disturbance which travels through space with a speed equal to $c/\sqrt{(\kappa\mu)}$, where c is the ratio of the electromagnetic to the electrostatic units of charge, κ is the dielectric constant, and μ is the magnetic permeability of the medium occupying the space. In a vacuum, $\kappa = \mu = 1$, and c is therefore the usually accepted symbol for the velocity of electromagnetic waves in vacuo.

In the latter half of the nineteenth century a large number of investigations were carried out on the determination of electric and magnetic quantities in terms of the c.g.s. system of absolute units; and the results of this work showed that for air or a good vacuum the quantity $1/\sqrt{(\mu\kappa)}$ closely approximated to the value of 3×10^{10} cm./s. Concurrently and independently, other workers had made direct measurements of the velocity of light and obtained results about 1 part in 2 000 less than the above value. Having regard to the accuracy of the experimental technique of the time, it is natural to find that 50 years ago this agreement was considered to be adequate to establish the facts that light constitutes an electromagnetic wave-motion, and that electromagnetic waves, very long in relation to those of light, could exist and might subsequently prove useful for a variety of purposes. I will now explore the matter a little further and examine the present state of our knowledge of the speed of propagation of electric waves of all lengths from the visual to the radio-frequency spectrum. Before doing so, however, let us first see why this knowledge is necessary to the radio engineer.

(3.2) The Need for Knowledge of Speed of Propagation

(3.2.1) Measurement of wavelength and frequency.

In the early days of wireless development, the waves employed were such that their length could be measured directly either on wires or in air, and it was customary to speak of the wavelength in use. This nomenclature was continued even after the wavemeters employed comprised a combination of an inductance and a capacitance, and the wavelength was deduced from a knowledge of these quantities. Later, it became evident that what was being measured was the frequency of the electrical oscillations in the circuit and not the wavelength of the radiation. At the present time our standard of reference in this field is one of frequency, and comprises either a standard tuning fork or a quartz crystal maintained in continuous vibration under carefully controlled conditions with the aid of subsidiary electrical circuits. Although from time to time much controversy—and if I may say so, some confusion—exists between radio engineers as to the proper use of frequency or wavelength, I would draw attention to the results of an agreement reached on an international basis in 1937, when the International Radio Communications Conference drew up a classification of radio wavelengths and frequencies, reproduced in Table 1.

Table 1

CLASSIFICATION OF RADIO WAVES AND FREQUENCIES

Designation of radio waves in terms of wavelength	Wavelength in metres	Designation of radio waves in frequencies	Frequency in kc./s.
Myriametre	above 10 000	very low	below 30
Kilometre	10 000 to 1 000	low	30 to 300
Hectometre	1 000 to 100	intermediate	300 to 3 000
Dekametre	100 to 10	high	3 000 to 30 000
Metre ..	10 to 1	very high	30 000 to 300 000
Decimetre	1 to 0·1	ultra-high	300 000 to 3 000 000
Centimetre	0·1 to 0·01	super-high	3 000 000 to 30 000 000

In drawing up this Table it was recognized that, in practice, centimetre and decimetre waves might be expressed in cm., and that frequencies above 3 000 kc./s. might be expressed in Mc./s.

The relationship between these radio waves and the infra-red and visible light spectra is shown by Table 2, which includes the lower two lines of Table 1.

Table 2

CLASSIFICATION OF VERY SHORT ELECTRIC WAVES

Designation of waves	Wavelength in cm.	Frequency in Mc./s.
Decimetre ..	100 to 10	300 to 3 000
Centimetre ..	10 to 1	3 000 to 30 000
Millimetre ..	1 to 0·1	30 to 300 $\times 10^3$
Infra-red .. (approximate upper limit)	0·05	600 $\times 10^3$
Visual spectrum	40 to 80 $\times 10^{-6}$	375 to 750 $\times 10^6$

In these Tables it has been assumed, for the sake of the obvious simplicity which results, that the velocity of the waves is accurately 3×10^{10} cm./s. But it must be remembered that the standard of measurement in the radio case is frequency, and although this standard is known to an accuracy of better than 1 part in 10^8, the wavelength cannot be similarly expressed unless the velocity term is known to the same accuracy, which, as will be seen below, is not the case.

(3.2.2) Study of wave propagation.

Certain types of wireless investigations assume a knowledge of the speed of travel of the waves employed to the accuracy required in the experimental work. For example, in studying the existence and properties of the ionosphere it is usual to measure the time interval between the emission of a group of waves and the receipt of the corresponding echo signal reflected from the ionosphere vertically above the observer. From this interval the height of the reflecting region is deduced on the assumption that in the non-ionized regions of the atmosphere through which the waves travel the speed is that appertaining to a vacuum.

Further, some methods of studying the direction of arrival of radio waves in either the vertical or horizontal plane are based upon the measurement of phase difference of the signal voltages induced in two aerial systems spaced a known distance apart. The phase difference is dependent upon the ratio of this distance to the wavelength, and, as already explained, the latter quantity is directly dependent upon the speed of travel of the waves over the path in question. When this path is along or close to the ground, it is important to know to what extent, if any, the speed of propagation is affected by the electrical properties

of the ground. That there is undoubtedly an effect is demonstrated by the fact that on medium wavelengths, in the region of a few hundred metres, wireless waves crossing a coast line from sea water to land at or near grazing incidence are deviated by a few degrees.[9] This deviation is towards the normal when the waves are passing from sea to land; and although the effect is most probably due to a difference in the velocity of the waves over the surface of the sea and the land respectively, this coastal deviation effect has not so far been satisfactorily explained.[10]

(3.2.3) Utilization of time signals and the measurement of longitude.

One of the earliest applications of wireless signalling was to the distribution of time signals from astronomical observatories connected up to appropriate wireless transmitting stations. By this means a service was provided of the greatest utility to ships at sea, and for the comparison of time measurement between observatories not normally in close and rapid communication with one another. An associated application is the determination of the difference of longitude between two points on the earth's surface. With the improvement of the technique of time-signal recording and measurement it was inevitable that, sooner or later, the question of the time of travel of the signal from the emitting to the recording station should be raised. In this case it is the actual time of transit of the waves between the two stations that is required rather than the speed of the waves, since the latter information is only of value if the path along which the waves travel is also known. During the past 20 years, however, considerable progress has been made in our knowledge of the mode of propagation of radio waves of various frequencies and over various distances, and with such knowledge of the path the speed of travel can be used directly to determine the time of transit.

(3.3) Determination of the Velocity of Light

During the latter half of the nineteenth century, various determinations of the velocity of light were made by Fizeau, Foucault and other investigators. These measurements showed that the velocity of light in air was in the neighbourhood of 3×10^{10} cm./s., and that the value was less in water than in air.

When we come to a study of the precise value of the velocity of light, we can turn mainly to the work of Prof. Michelson who, over a period of some 50 years, conducted research in the United States of America in this subject, in co-operation with various colleagues. The most recent and accurate measurements were actually in progress when Michelson died in May, 1931,[11] and I think it may be of interest to refer very briefly to this work and the results obtained from it as recorded in the paper published by Michelson, Pease and Pearson[12] in 1935. The equipment utilized in this experimental work is notable, by reason of the fact that the path traversed by the light waves was enclosed in a steel tube, 1 mile long and 3 ft. in diameter, this tube being evacuated to a pressure of from 0·5 to 5·5 mm. mercury. The schematic arrangement of the optical system of the apparatus used is illustrated in Fig. 1, taken from the paper referred to above. Light

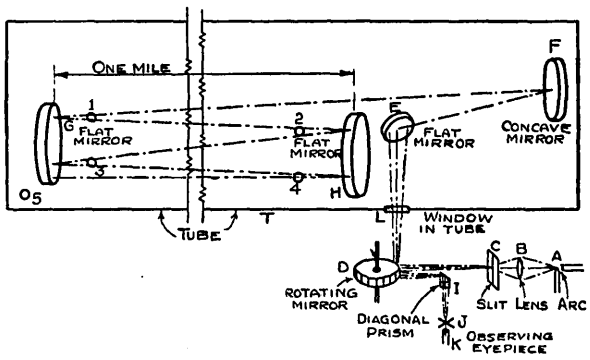

Fig. 1.—Optical arrangement for velocity determination in vacuum by rotating-mirror method (A. A. Michelson, F. G. Pease and F. Pearson).

from an illuminated slit C is reflected from the upper half of a rotating mirror D, through a window L in the side of the steel tube just described. By multiple reflections between the mirrors G and H, the light waves were caused to traverse a total path length of the order of 8–10 miles before being returned through the window L on to the rotating mirror D. The optical adjustments were such that the returning beam of light was reflected from the lower half of the rotating mirror D and so through the prism I to the observing eyepiece JK. In the latest experiments the rotating mirror had 32 faces and was driven at such a speed that the outgoing and returning beams of light were reflected from adjacent faces. As the mirror starts to rotate, the image observed in the eyepiece gradually passes from the field of view and reappears in the other side of the field only when the rotating mirror approaches its proper speed. If the speed is so adjusted that the image is in the centre of the field of view, it is then known that the time taken for the light to traverse its path of several miles is equal to 1/32 of the time of rotation of the mirror.

The distance traversed by the light was obtained by reference to a carefully measured base line adjoining the tube, while the time was measured stroboscopically by use of a tuning fork synchronized with the rotating mirror. The tuning-fork frequency was measured by reference to a free pendulum, which itself was checked against two chronometers, one of which was driven by a quartz-crystal oscillator. In this way nearly 3 000 determinations of velocity were made between September, 1929, and March, 1933, and the simple mean value of this is 299 774 km./s., with an average deviation of 11 km./s.

It is interesting to note that the development of radio-frequency technique has assisted and facilitated the measurement of the velocity of light on a laboratory scale. The method which has been employed by W. C. Anderson[13] utilizes the principle first applied by Karolus and Mittelstaedt[14] of modulating the light beam with a radio frequency through the agency of a Kerr cell. R. A. Houston[15] has also described a method which utilizes a quartz crystal vibrating at a frequency of 100 Mc./s. as an intermittent grating giving brilliant diffraction bands for the light transmitted through it. In Anderson's experiments the incident beam of light after passing through a pair of crossed Nicol prisms traversed a Kerr cell containing a suitable organic liquid subjected to an alternating electric field at a frequency of from 14 to 56 Mc./s. The light then passed through

another Nicol prism pair, and so the emergent beam was modulated in amplitude at the radio frequency mentioned. This beam was split into two parts, one of which was directed immediately on to a photo-electric cell, and the other arrived at the same cell after traversing a path of from 10 to 20 metres between suitable mirrors (see Fig. 2).

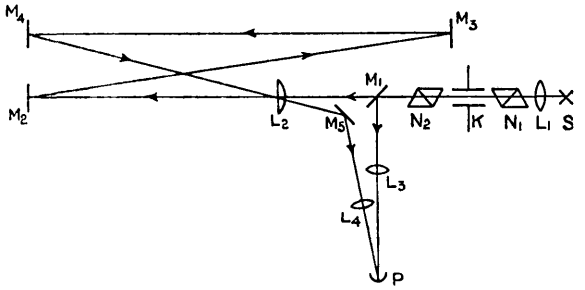

Fig. 2.—Optical arrangement for velocity determination by radio-frequency modulation (W. C. Anderson).

The radio-frequency output from the photo-electric cell was amplified and detected in a suitable receiver, provided with a beat-frequency oscillator to give an audible output in a pair of telephones. The length of the main optical path could be adjusted until the output signal was of minimum intensity, when it was known that the two beams of light arrived at the photocell 180° out of phase, and thus that the difference of path traversed by the beams corresponded to an odd multiple of half-wavelengths at the modulation frequency. The determination of velocity thus depended upon the accurate measurement of the linear differences of path, which was all inside the laboratory, and the radio modulation frequency which could be referred directly to a laboratory frequency standard, in this case a quartz oscillator. Anderson considered that each of these measurements was determined to a few parts in a million; and he gave as the result of 651 observations of velocity the mean value of 299 764 km./s. to an accuracy of ± 15 km./s. in a vacuum. In a later paper, Anderson[13(b)] describes various improvements made to his optical and measuring system, which led to an increase in the accuracy of the measurements. He also draws attention to the necessity for correcting both his own results and those of other investigators for the group velocity delay of the light waves in passing through the various glass lenses and mirrors involved in the system. In this later work 2 895 observations were made, giving a mean value for the velocity in a vacuum of 299 776 km./s. with a variation of ± 14 km./s.

The results obtained in the measurements of the velocity of light described above are collected in Table 3.

It will be seen that the measured value for the velocity differs from the conveniently assumed value of 3×10^{10} cm./s. by some 750 parts in 10^6.

Since for radio purposes we are rarely concerned with wave transmission in a vacuum, the above values will require to be multiplied by $1/\sqrt{\kappa}$, where κ is the dielectric constant of the medium in question. For air under normal atmospheric conditions at the earth's surface in this country, corresponding to a pressure of 760 mm. mercury, a temperature of 15° C. and a relative humidity of 70 %, the value of κ is about 1·0007, and thus the corresponding value of the velocity will be reduced to 299 670 km./s.

Table 3

RECENT MEASUREMENTS OF THE VELOCITY OF LIGHT (VALUES REFER TO TRANSMISSION IN A VACUUM)

Date	Observers	Velocity in cm./s.	Accuracy of measurement	Difference from $c = 3 \times 10^{10}$
1931–33	Michelson, Pease and Pearson	$2{\cdot}99774 \times 10^{10}$	$0{\cdot}4$ in 10^4	$-7{\cdot}5$ in 10^4
1936–40	Anderson	$2{\cdot}99776 \times 10^{10}$	$0{\cdot}5$ in 10^4	$-7{\cdot}5$ in 10^4

It is sometimes suggested that measurements of the velocity of light showed a variation in value with time, but one of Anderson's papers already referred to [13(b)] contains a graphical representation of all the measurements made since 1870, and this indicates that while there has been considerable improvement in accuracy there has been no consistent variation with time.

(3.4) The Speed of Wireless Waves

Let us now review the extent of our knowledge of the speed at which electric waves in the radio-frequency spectrum travel, and the variation, if any, to which they are subject by conditions such as proximity to the earth's surface and whether this is sea or land. Until a few years ago, most of the methods used by radio investigators measured, or attempted to measure, not the velocity or speed of travel of the waves, but the time of transit between the sending and receiving stations. Unless the path over which the waves are transmitted is kept relatively short, a determination of velocity will require an exact knowledge of the path followed by the waves, and this may involve passage through one or other of the ionospheric reflecting regions. As our investigations of the mode of propagation of waves around the earth progress, we can specify more and more closely the exact route followed by radio waves at any given time, but even at this date measurements involving this knowledge cannot lead to a velocity determination to a high degree of accuracy. Indeed, it would probably be better to determine the velocity by other means and then use this knowledge to further our study of the propagation conditions.

Another difficulty which lies in the way of determining wave velocity in the radio-frequency spectrum is that of producing the equivalent of a mirror which, in the manner similar to its use in the case of light, will reflect the waves with a known phase change and with a negligible time delay. The use of an aerial system, with its associated energizing apparatus, involves a delay of some milliseconds, which is comparable with the travel of the waves over hundreds of miles.

It is for such reasons as the above that many of the determinations in the past have led to an inaccurate estimation of the speed of travel of wireless waves. For example, some methods have been based on a comparison of time signals received from European and American stations; the time of transit of the waves is in this case of the order of 20 millisec., and it is necessary that the deter-

mination of this time interval shall not be made by methods involving the introduction of corrections for personal equations of the same order of magnitude, relay lags with uncertainties of the order of 10 millisec., and other cumulative sources of errors, each of comparable magnitude.

Until about 1935, investigators using methods not free from these sources of error obtained values appreciably less than the known velocity of light, even on very long wavelengths, in which case the path might be assumed to be reasonably well defined. In some cases (e.g. Colwell[16]) it was suggested that the speed at which the radio waves travelled was of the order of one-half or two-thirds that of the velocity of light, but in later work Colwell[17] and his collaborators appear to have been more successful in eliminating important sources of error.

Subsequent to these publications various investigators obtained evidence which showed that for transmission over short paths along or near to the ground the velocity of radio waves could not differ by more than a few per cent from the velocity of light. For example, Savelli,[18] using a wavelength of about 38 cm., compared the standing waves produced over a path of 5 m. along the ground between a transmitting dipole and a reflecting sheet, with the standing waves maintained by the same source on a Lecher wire system. In this way he was able to demonstrate that the phase velocity of the waves in the two cases was the same to within 2 or 3 %. Following this work, Lo Surdo[19] and his colleagues used an interference method to demonstrate that with waves 15·2 cm. in length the velocity of propagation is independent of the nature of the surface, whether this be fresh water or an asphalt road, and also of the height of the wave path above the surface up to some 15 wavelengths. In this case it was concluded that the phase velocity of the waves along two paths at different heights was the same to within 1 part in 10^4.

A. L. Vitter and L. C. Brieger[20] have also described a velocity determination by measuring the wavelength in air of radiation from a transmitter driven from the fourth harmonic of a crystal-controlled oscillator at a frequency of about 114 Mc./s. (wavelength 2·63 m.). Standing waves were obtained between the transmitting aerial and a plane reflecting sheet, and the positions of the maxima and minima measured over a distance of 28 metres. It was considered that the results agreed with the velocity of light to within about 2 %.

In 1937 W. Ross and E. C. Slow,[21] of the Radio Department of the National Physical Laboratory, made a determination of the phase velocity of radio waves transmitted along the surface of the ground, using apparatus already developed and in use for other investigations. The principle of the method employed is illustrated by Fig. 3. A pair of similar aerials A and B are set up at a known distance apart in the line of propagation of waves from a local source. Each aerial circuit was connected to an amplifier and the two resulting outputs were applied to the two pairs of deflecting plates of a cathode-ray tube. The amplifiers and aerial circuits were first adjusted so that when equal and co-phasal fields existed at the two aerials, the figure traced on the oscillograph screen was a straight line at 45° to the axes of deflection of the spot. This preliminary adjustment was carried out by radiating a signal on the frequency used in the measurements from an

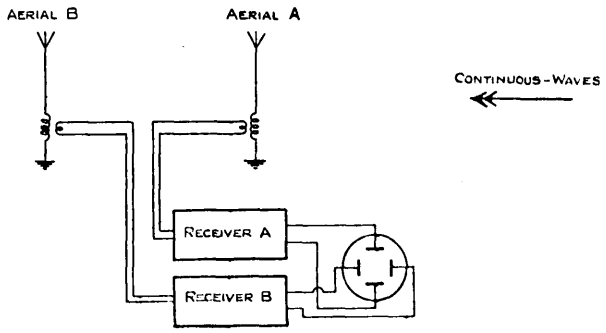

Fig. 3.—Measurement of phase velocity of electromagnetic waves (W. Ross and E. C. Slow).

oscillator located midway between the aerials. Next, continuous-wave radiation was received from a remote source placed on the line joining the aerials, and from the elliptical trace which was in general produced on the oscillograph tube it was possible to determine the phase difference between the currents in the aerials, and so the phase velocity of the waves passing between them. The average result for this velocity over the wavelength range 20 to 120 m. (2·5 to 15 Mc./s.) was $2{\cdot}95 \times 10^{10}$ cm./s., the overall experimental accuracy of the measurements being considered to be about 5 %.

For a longer distance of transmission over land of 60 km. F. T. Farmer and H. B. Mohanty[22] showed that the velocity of propagation for a wavelength of 166 m. (1·8 Mc./s.) is within 6 or 7 % of the velocity of light. Their measurements were made with high-frequency impulses and therefore refer to the group velocity of the waves; but their results are consistent with the phase velocity measurements of other workers.

A most comprehensive investigation of the velocity of medium radio waves was carried out during the years 1934–35 by a group of workers in the Laboratories of the U.S.S.R. under the direction of Profs. L. Mandelstam and N. Papalexi; and the details and results of these investigations were published in a collection of papers in 1937.[23] The method employed comprises a determination of the time of transit of waves between a sending and reflecting station by measuring the phase difference between the two sets of waves the ratio of whose frequencies is rational. The subsidiary investigations included the development of methods and instruments for measuring the phase difference between harmonic oscillations of different frequencies, and the study of the phase displacement introduced by high-frequency amplifiers.

A schematic arrangement of the method employed is shown in Fig. 4. The main station I radiates waves on a frequency f_1, a voltage corresponding to the outgoing frequency being applied to one pair of plates of a cathode-ray oscillograph. At the subsidiary or "reflecting" station II the incoming waves are received, then submitted to a frequency-change in a simple but non-harmonic ratio (e.g. 3 : 2); then the oscillations of the new frequency f_2, after amplification, are transmitted from station II back to station I. The cathode-ray oscillograph depicted at station II is used for the control of the phase difference between the incoming and outgoing waves, this phase difference being maintained constant during all experimental observations. The waves of frequency f_2 are re-

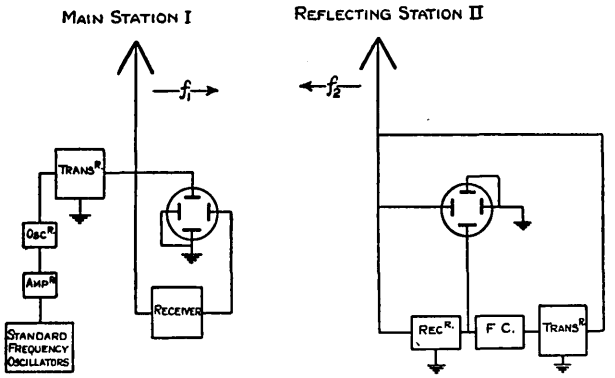

Fig. 4.—Measurement of group velocity of electromagnetic waves (L. Mandelstam and N. Papalexi).

ceived at station I and the resulting oscillations suitably amplified for application to the other pair of plates of the oscillograph at this station, so that the phase of the incoming waves may be compared with that of the waves originally emitted on a frequency f_1. Under the conditions outlined, the trace on the screen of the oscillograph at I will be a Lissajous figure corresponding to the frequency ratio 3/2, its exact form depending upon the total phase difference of the outgoing and arriving waves. This phase difference may be expressed in the form

$$\phi_T = \phi_0 + \phi_1 + \phi_2 + \phi_3 \quad . \quad . \quad . \quad (1)$$

where ϕ_0 = phase displacement suffered by the waves over the return path between stations I and II, ϕ_1 = phase difference introduced by the receiver at II, ϕ_2 = phase difference introduced by the transmitter at II, ϕ_3 = phase difference introduced by the receiver at I.

If we can separate ϕ_0 from the above measurements, we have

$$\phi_0 = 4\pi fd/v. \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where f is the frequency of the waves, d the distance between aerials I and II, and v the velocity of the waves over the path d.

This separation of ϕ_0 was made by measuring the values of ϕ_1, ϕ_2 and ϕ_3 for the individual components of the apparatus in question, by using a phase-measuring technique which was developed to an advanced stage by E. Schegolev,[23(c)] and C. Viller,[23(d)] two of the investigators associated with the group referred to above. An instrument termed a "phase deviometer" was constructed specially for use in the velocity determinations, and this instrument includes simple scale arrangements for reading the phase indications directly off the Lissajous figures traced on the screen of the cathode-ray tube.

The phase displacement ϕ_0 will in general comprise several complete cycles and may be expressed in the form

$$\phi_0 = 2\pi(n + m) \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where n is an integer and m is a fraction.

In order to evaluate these two quantities, the frequency f_1 of the waves radiated from station I is varied continuously over a small range, while the frequency of the synchronized waves from II is also changed so as to keep the frequency ratio constant, a matter that is easily checked by observation of the Lissajous figure on the screen at II. This frequency change is carried out between the limits accurately set by two quartz-crystal standard frequency oscillators incorporated in the equipment at station I, so that the frequency range covered is known to a high order of accuracy. As the frequency of station I is varied in this manner between the limits set by the standard frequency oscillators, the number of complete cycles of phase-angle change is counted on the oscillograph at I, and the final fractional phase angle is also measured. In this way the total phase change ϕ_0 is measured [eqn. (3)], and so the velocity of transmission of the waves determined from equation (2). This technique is similar to that used in 1925 by E. V. Appleton and M. A. F. Barnett[24] to measure the height of the ionospheric regions, using a known value for the velocity of the waves.

With the aid of the method and procedure outlined above, an investigation of the velocity of medium radio waves under a variety of conditions has been described by C. Viller and E. Schegolev[23(b)] in one of the group of papers to which reference has already been made. In these experiments the frequencies chosen for f_1 and f_2 were nominally 870 and 1 305 kc./s. (wavelengths 345 and 230 m.), while the frequency difference between the standard frequency oscillators was of the order of 30 kc./s. These oscillators were of the quartz-crystal type, and were either temperature-controlled or corrected for temperature variations during the periods of observation. The paths over which experiments were conducted varied from some 10 to 40 km. in length; in some cases the two observing stations were installed on mountain peaks in the Caucasus approaching 1 000 m. in height, to give an approximation to free-space conditions, while in other cases the experiments were conducted with transmission paths close to the ground, and also over the Black Sea and over a lake of fresh water. Those who are interested will find the details of these experiments described very completely in the relevant papers, but I must here confine myself to a very brief statement of the results, since this is our chief interest in connection with this survey.

The accuracy of the measurements carried out by the methods described above depends essentially on the measurement of the two quantities, the phase displacement ϕ_0 and the length of path d traversed by the waves between the stations. The total phase displacements during the frequency-change process ranged from a few hundred to several thousand degrees, and the investigators were able to measure these to within 3° or 4°; so that the accuracy of phase measurement was of the order of 1 or 2 parts in 10^3 in the most favourable cases. The distance measurements were carried out by standard geodetic survey methods, and appear in the most favourable cases to have been determined to an accuracy somewhat better than 1 part in 10^3 (0·1 %). This implied that the centres of radiation of the aerial systems were known to a high order of accuracy, and to facilitate this the aerials at both stations were of the vertical-umbrella type.

The mean results obtained in the various sets of experiments for the velocity of the medium radio waves used all lie within the limits of 2·990 and 2·995 × 10^{10} cm./s. for transmission over clear air path, or over sea or fresh water. As these limits are within the accuracy of the measurements, no definite conclusions can be drawn as to the effect of a salt or fresh water path on the velocity of propa-

gation. In the case of transmission overland, a somewhat lower value of $2{\cdot}950 \times 10^{10}$ cm./s. was obtained, although this would appear to be subject to some uncertainty in determining the true path of transmission, owing to various intervening obstacles.

Although the work just described has enabled a valuation for the wave velocity to be obtained, much of this and other investigation work has been directed by Mandelstam and Papalexi towards the development of what is termed an "interference range-finder." More recently than the work referred to above, some papers have been published by J. L. Alpert, W. W. Migulin and P. A. Riasin,[25] in which the nature of the electromagnetic field near an aerial, and the effect of various conditions on the velocity of propagation to various distances, have received special attention. It appears that there is reason to suppose that the phase velocity of radio waves propagated over a flat and uniform surface is not constant, but may vary within a radius of three or four wavelengths from the source; this disturbance gradually disappears until, at a radius of some 50 wavelengths, the velocity is sensibly equal to its free-space value. Experiments have also been carried out to ascertain whether there is any dispersion in the transmission of waves over land and sea, in the range of wavelengths 120 to 660 m. The results of such experiments indicate that, for example, the velocity at wavelengths of 300 and 450 m. cannot differ by more than 0·07% for oversea transmission, whereas over dry land a difference of a few tenths of 1% is possible. It is stated that balloon experiments have shown that the effect of the earth's surface on the field does not extend beyond a height of four or five wavelengths for the medium waves used. All this work would appear to be closely connected with Sommerfeld's classical investigations of the propagation of electromagnetic waves over the earth's surface, and to warrant considerable further study in connection with various radio problems and applications. It forms an interesting example of the manner in which fundamental investigations conducted from an apparently solely academic viewpoint may, in time, come to have important practical applications.

CONCLUSIONS

In Section (3) I have tried to present a picture of the existing state of knowledge concerning the velocity of propagation of electromagnetic waves, whether these correspond in wavelength to the visible part of the spectrum or to that part, now very extensive, used for radio communication and other applications. The velocity of light waves is known with considerable precision, and its value in vacuum may be taken as $2{\cdot}99775 \times 10^{10}$ cm./s., the modified value for light propagated through air under normal atmospheric conditions at sea level in this country being $2{\cdot}99670 \times 10^{10}$ cm./s.; the accuracy of measurement of these values is about 0·5 part in 10^4. It will be observed that the velocity value in air differs from the nominal figure of 3×10^{10} cm./s. by about 0·1%. Modern radio-frequency technique has proved of considerable use in recent determinations of the velocity.

When we come to the radio-frequency portion of the spectrum, the methods so far used for the determination of the velocity are much less accurate than this: and it may be stated that within the limits of the experimental accuracy so far attained, which is not better than 0·1%, the velocity of propagation of medium radio waves is about $2{\cdot}990 \times 10^{10}$ cm./s. The experimental evidence so far available indicates that this value for the velocity is the same for all radio wavelengths within the accuracy specified above. There is some evidence that the phase velocity may be reduced below this value near the transmitting aerial, and it may also be modified when transmission takes place close to the surface of the earth; but it seems doubtful whether this variation from the free-space value amounts to more than the experimental accuracy, except where obstacles such as trees and mountains intervene in the path of propagation. In this case it is not necessarily the velocity which has altered, but rather that the path traversed has been increased.

This discussion of our present knowledge leaves the problem of the measurement or calculation of the actual time of transit of radio waves between sender and receiver still open to investigation. This type of information may be required for a number of purposes such as the use of time signals for the comparison of chronological standards and for the determination of differences of longitude. For the solution of this problem a knowledge of the free-space speed is only one requirement; it still needs a precise specification of the actual path, rectilinear or otherwise, followed by the waves, and of any modification to the velocity value produced by atmospheric or ionospheric conditions.

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